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Components Irradiation Test 3

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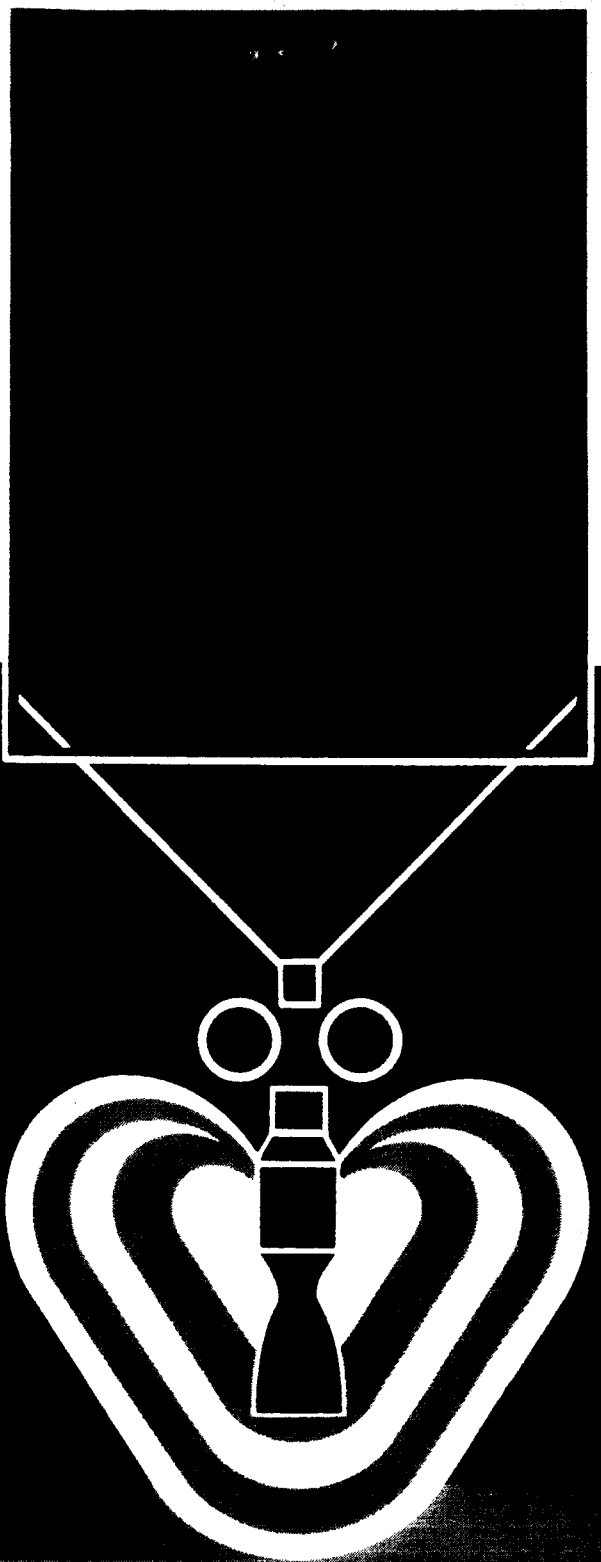

Georgia Nuclear Laboratories

LOCKHEED-GEORGIA COMPANY -- A Division of Lockheed Aircraft Corporation

ER-7360
(ND-3013)

COMPONENTS IRRADIATION TEST NO. 3

Field Effect Transistors

15 June 1964

Prepared for:

GEORGE C. MARSHALL SPACE FLIGHT CENTER

Prepared by:

Georgia Nuclear Laboratories

GEORGIA NUCLEAR LABORATORIES
Lockheed-Georgia Company - A Division of Lockheed Aircraft Corporation

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FOREWORD

This report is submitted to the Astrionics Laboratory of the George C. Marshall Space Flight Center, National Aeronautics and Space Administration, Huntsville, Alabama, in accordance with the requirements of Task Order No. ASTR-LGC-11 of Contract No. NAS 8-5332. The report is one of a series describing radiation effects on various electronic components. This particular report concerns three types of field effect transistors. The test was performed by the Georgia Nuclear Laboratories, Lockheed-Georgia Company.

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1.0 SUMMARY

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Three types of field effect transistors were subjected to a radiation environment at a controlled temperature of $30^{\circ}C \pm 2^{\circ}C$. Sample size was 20 specimens of each type. Irradiation was continued until the specimens had accumulated an average integrated flux of 5.0×10^{14} n/cm^2 plus a gamma dose of 5.8×10^6 r. During the irradiation measurements were made to define the g_m and I_{GSS} parameters.

Test results indicated:

(1) The g_m parameter of the transistors was degraded by the nuclear radiation. The mean g_m of each group had decreased 50% after a total radiation exposure as tabulated below:

Type	Manufacturer	n/cm^2 +	r
FE 200	Amelco	1.1×10^{14}	1.8×10^6
2N2841	Siliconix	4.1×10^{14}	4.9×10^6
2N2844	Siliconix	2.3×10^{14}	3.0×10^6

A slight correlation was noted between low values of initial g_m and early failure.

(2) The I_{GSS} parameter of the FE 200 and 2N2844 types was increased by nuclear radiation. The I_{GSS} of the 2N2841 type remained below instrument range throughout the test.

Authors

2.0 INTRODUCTION

The experiment described in this report is the third irradiation of electronic components and is the seventh in a series of radiation effects tests on electronic equipment,circuits, and components contemplated for use on a nuclear space vehicle. Since the use of equipment on this vehicle is contingent upon its ability to withstand the nuclear environment, the Astrionics Laboratory of the Marshall Space Flight Center has undertaken to assure that Government furnished or specified equipment will survive this environment. The equipment is to be subjected to the expected nuclear environment as simulated at the Georgia Nuclear Laboratories. Measurements made on the equipment during the irradiation will describe its radiation tolerance.

The subject of this test is three types of field effect transistors.

3.0 TEST PROCEDURE

The test specimens were supplied by the Astrionics Laboratory of the Marshall Space Flight Center. They were exposed to a nominal gamma dose of 5.5×10^5 r behind a neutron attenuator shield. The shield was then removed and the test was resumed until a nominal integrated neutron flux of 5.0×10^{14} n/cm^2 was accumulated. During the test all specimens were mounted in a controlled temperature chamber held at 30° C $\pm$ 2°C. Before, during, and after the test, measurements necessary to determine the parameters listed in Table 1 were made. Other measurements made during the test were those necessary to define the nuclear and temperature environments.

3.1 TEST SPECIMENS

The specimens tested are listed in Table 1. All specimens were breadboard mounted by the Astrionics Laboratory. All specimens were "new" units and had only been subjected to receiving inspection. Manufacturers' specifications for the specimens are shown in Table 2. Instrumentation circuity and mounting hardware were provided by GNL.

3.1.1 Specimen Mounting

The specimen breadboards were mounted vertically on the test fixture to equalize, as much as possible, the radiation flux distribution over the test specimens. Figures 1 and 2 show the relative positions of the specimens as mounted. The test fixture was placed in a controlled temperature chamber adjacent to the reactor.

3.2 TEST SPECIMEN MEASUREMENTS

A complete set of data was taken at 30°C prior to reactor start-up to establish baseline data for the test. During the irradiation, measurements were made at all reactor power settings.

Measurements were also made:

(a) during reactor shutdown for removal of the water shield,

(b) immediately after reactor shutdown upon completion of the irradiation, and

(c) approximately 12 hours after completion of the irradiation on specimens which did not fail during irradiation.

All measurements were made with the test fixture in place at the Reactor Facility.

3.3 INSTRUMENTATION

3.3.1 Field Effect Transistor Measurement Circuity

The circuit shown in Figure 3 was used to perform the transistor measurements with the GNL Digital Voltmeter Data Logging System. The sources of all the transistors were commoned on the test boards and the Gate and Drain of each transistor were commutated. Each measuring sequence consisted of measuring the Drain-Source voltage drop at three gate bias levels and utilizing the prescribed V_{DD} and load resistance as outlined in Table 1. The Gate leakage of each transistor was measured as shown in Figure 4, using the prescribed V_{GS}.

3.4 TEST ENVIRONMENT

3.4.1 Pressure

The test was conducted at atmospheric pressure.

3.4.2 Temperature

The specimens were irradiated in a temperature controlled environment of $30^{\circ}C \pm 2^{\circ}C$, except that near the end of the test the temperature rose gradually to $38.5^{\circ}C$ due to a combination of gamma heating and high ambient temperature. Figure 5 is a graph of the environmental temperature versus integrated neutron flux.

3.4.3 Nuclear

All test specimens were subjected to a simulated nuclear vehicle environment. Nuclear irradiation was performed in two phases. The first phase was conducted behind a 20" water shield which served as a neutron attenuator. The second

phase was conducted with no shielding. The neutron/gamma ratio behind the shield was about 10^6 nvt/r, as compared to about 10^8 nvt/r without the shield. The neutron/gamma ratio predicted for the instrumentation unit of a nuclear vehicle is about 2×10^5 nvt/r. During the irradiation, both neutron and gamma radiation were monitored and recorded.* Locations of gamma and neutron monitors are shown in Figure 2. Isoline radiation flux plots were made for the test panel to aid in data reduction.

* A more detailed description of the GNL nuclear measurement system is contained in previous reports; viz. "Components Irradiation Test No. 1, "ER-6785, Georgia Nuclear Laboratories, Dawsonville, Ga.

4.0 METHOD OF DATA ANALYSIS

The GNL Data Logging System recorded the parameter measurements in type-written digital form and simultaneously punched the data in 5-channel perforated tape. A tape-to-card converter was used to transfer the data to IBM cards which were then programmed into an IBM 7094 computer to yield I_{GSS}, g_m, and g_{m_n} (normalized g_m). Normalization of g_m was accomplished by dividing each g_m value by its corresponding pre-irradiation value. Since data measurements could not be made simultaneously on all specimens, and since the flux rate was not uniform over the entire test panel, it was necessary to program the data for each specimen separately to provide a plot of the measurement under consideration versus radiation exposure. Parameter values were then calculated from the plot at selected radiation exposure levels and processed for group medians and envelope limits.

The g_m parameter was computed from the difference between the mean of i_{DS} values at three different resistance loads with $+V_{GS}$ and the mean of i_{DS} values at the same three resistance loads with $-V_{GS}$.

The mean parameter value for a data group, where shown, was computed by adding the individual specimen parameter values and dividing the sum by the number of specimens.

The median parameter value for a data group (that value which divides a distribution so that an equal number of items is on either side of it) was determined graphically from a plot of the individual specimen parameter values on arithmetic probability paper. The limits of the 68% envelopes were determined by picking off those values within which were contained 34% of the specimens next above the group median value and 34% of the specimens next below the group median value. The limits of the 95% envelope were found in a similar fashion.

In those cases where the parameter of an individual specimen behaved significantly differently from the group median, these "unusual" specimens have been portrayed in separate figures.

Radiation environmental data shown on the figures' abscissae were obtained by integrating with respect to time, the gamma dose rates and neutron flux rates.

Those figures which show "Percent Failed Versus Integrated Neutron Flux" were prepared after the procedure described by Mr. Frank W. Poblenz in an article entitled "Analysis of Transistor Failure in a Nuclear Environment" which appeared in Volume NS-10, Number 1, January 1963, of the IEEE Transactions on Nuclear Science. This type of presentation enables the circuit designer to predict the radiation level at which any given percentage of the particular component will equal or exeed the failure criteria.

Copies of the reduced data from which the graphs were prepared are on file in the Astrionics Laboratory of the George C. Marshall Space Flight Center, NASA, Huntsville, Alabama, and in the Georgia Nuclear Laboratories, Lockheed-Georgia Company, Dawsonville, Georgia.

5.0 TEST DATA AND DISCUSSION OF RESULTS

The test data have been presented herein in graphical form. The radiation exposure is, in all cases, a combination of neutrons and gammas. The abscissa scale on each of the graphs is accumulated neutrons/cm^2 greater than 0.5 mev. However, the coincident accumulated gamma dose (r) is also indicated at those points where changes in the reactor power rate occurred. It is important to remember that the total radiation exposure consists of both neutrons and gamma, and that each may contribute, in varying degrees, to the degradation of a component's parameter.

5.1 TRANSISTOR, TYPE FE 200

Seventeen of the 20 specimens were operating satisfactorily at the beginning of the test. Figure 6 shows the median normalized g_m of the group and its behavior during exposure to radiation. There was a slight increase in g_m during the first part of the test. Degradation of g_m below the pre-irradiation value began at about 8.5×10^{11} n/cm^2 and continued steadily during the remainder of the test. The median g_m for the group had decreased to 50% of its pre-irradiation value at about 1.1×10^{14} n/cm^2. With respect to g_m no specimen differed significantly from the median. Figure 7 shows that the failure points ranged from 7.6×10^{13} n/cm^2 to 1.3×10^{14} n/cm^2.

The pre-irradiation value of g_m for each specimen is tabulated below in ascending order along with the order of specimen failure:

Pre-Irradiation g_m	Order of Failure
447.0	2
525.5	6
564.5	8
575.1	3
584.8	1
592.2	10
629.0	14

Pre-Irradiation g_m	Order of Failure
646.9	5
653.3	4
658.6	13
665.2	16
668.0	11
672.1	15
690.9	12
731.0	17
757.2	7
786.2	9

This tabulation offers some evidence that the specimens with low g_m values are apt to fail first in a radiation environment.

Figures 8 through 12 show characteristic curves of i_{DS} versus V_{DS} for one specimen of the group at the indicated radiation levels. This particular specimen had a pre-irradiation g_m of 653.3 μmhos.

Figure 13 shows the median I_{GSS} of the group versus integrated neutron flux. No radiation rate effect is indicated by the data. There was some annealing of this parameter during the 42 minutes at zero reactor power for removal of the water shield.

5.2 TRANSISTOR, TYPE 2N2841

Nineteen of the 20 specimens were operating satisfactorily at the start of the test. Figure 14 shows the median normalized g_m for the group versus radiation exposure. At 4.0×10^8 n/cm^2 twelve of the specimens had g_m values greater than the pre-irradiation value while six had g_m values less than the pre-irradiation value (one specimen had a g_m value at this point which was evaluated as spurious). The normalized g_m value for most of the specimens followed the behavior of the group median; however, two specimens exhibited "unusual" characteristics. These are shown in Figure 15. The range of radiation exposure over which the

failures occurred was 2.9×10^{14} n/cm^2 to 5.0×10^{14} n/cm^2 (Figure 16). The normalized g_m value for two of the specimens was slightly greater than 0.5 immediately after completion of the irradiation, but had dropped to less than 0.5 at the time of the post-test measurements about 12 hours later.

The pre-irradiation value of g_m for each specimen is tabulated below in ascending order along with order of failure:

Pre-Irradiation g_m	Order of Failure
67.7	1
77.0	2
80.4	7
82.2	13
83.2	3
83.5	4
83.5	10
83.7	9
89.4	8
90.2	12
91.2	11
91.2	18*
99.7	5
102.6	16
104.4	17
105.2	15
108.6	6
121.6	14
123.1	19*

* Projected order of failure

From this data it appears that the specimens with the lower g_m's have a tendency toward earlier failure in a radiation environment.

Figures17 through 21 are characteristic curves of i_{DS} versus V_{DS} for one specimen of the group at the indicated radiation levels. This specimen had a pre-irradiation g_m of 90.2 μ mhos.

Throughout the test the I_{GSS} values for this type transistor were too small to be measured by the instrumentation used. This instrumentation had a maximum sensitivity of 10^{-9} amps.

5.3 TRANSISTOR, TYPE 2N2844

Seventeen of the 20 specimens were operating satisfactorily at the start of the test. Figure 22 shows the normalized median g_m for the group versus radiation exposure. The normalized g_m of each specimen followed the median reasonably well. The range of failure was from 1.5×10^{14} to 3.1×10^{14} n/cm^2 (Figure 23).

The pre-irradiation value of g_m for each specimen is tabulated below in ascending order along with order of failure:

Pre-Irradiation g_m	Order of Failure
1488.7	3
1595.4	1
1725.3	9
1731.8	2
1818.1	6
1905.6	11
1920.0	17
1957.5	7
1963.7	5
2000.1	8
2027.7	16
2056.1	12
2057.9	4

Pre-Irradiation g_m	Order of Failure
2068.8	10
2091.4	15
2134.7	14
2212.3	13

There appears to be some correlation between low values of g_m and early failure.

Figures 24 through 28 are characteristic curves of i_{DS} versus V_{DS} for one specimen of the group at the indicated radiation levels. The specimen shown had a pre-irradiation g_m of 1963.7 μ mhos.

Figure 29 shows the median I_{GSS} for 15 specimens of this type. The I_{GSS} data from two of the seventeen satisfactory specimens was not useable. The data indicated no radiation rate effect on the I_{GSS} parameter. There was some annealing during the 42 minutes at zero reactor power for removal of the water shield. It should be noted that the majority of the specimens exceeded the manufactuer's specification of 30 na maximum I_{GSS} prior to failure of the first specimen due to decreased g_m.

TABLE 1 TEST SPECIMENS AND TEST CONDITIONS

Board No.	Description	Number Tested	Test Conditions	Parameter
1	Field Effect Transistor FE-200 N-Channel Silicon Planar Amelco	20	V_{DD} = 30 V V_{GS} = 0, +.5V, -.5V	g_m
			V_{DS} = 0 V_{SG} = 30V	I_{GSS}
2	Field Effect Transistor 2N2841 P-Channel Silicon Planar Diffused Unipolar Siliconix Corp.	20	V_{DD} = -5V V_{GS} = 0, +.5V, -.5V	g_m
			V_{DS} = 0 V_{GS} = 5V	I_{GSS}
3	Field Effect Transistor 2N2844 P-Channel Silicon Planar Diffused Unipolar Siliconix Corp.	20	V_{DD} = -5V V_{GS} = 0, +.1V, -.1V	g_m
			V_{DS} = 0 V_{GS} = 5V	I_{GSS}

TABLE 2 MANUFACTURERS' SPECIFICATIONS FOR TEST SPECIMENS

Transistor Type	g_m	I_{GSS}
FE 200	1000 μmhos max.	I_{DGO} max. .5 na V_{DG} = 30V I_S = 0 I_{SGO} max. 1 na V_{SG} = 30V I_D = 0
2N2841	60 μ mhos min.	max. 1 na
2N2844	1400 μmhos min.	max. 30 na

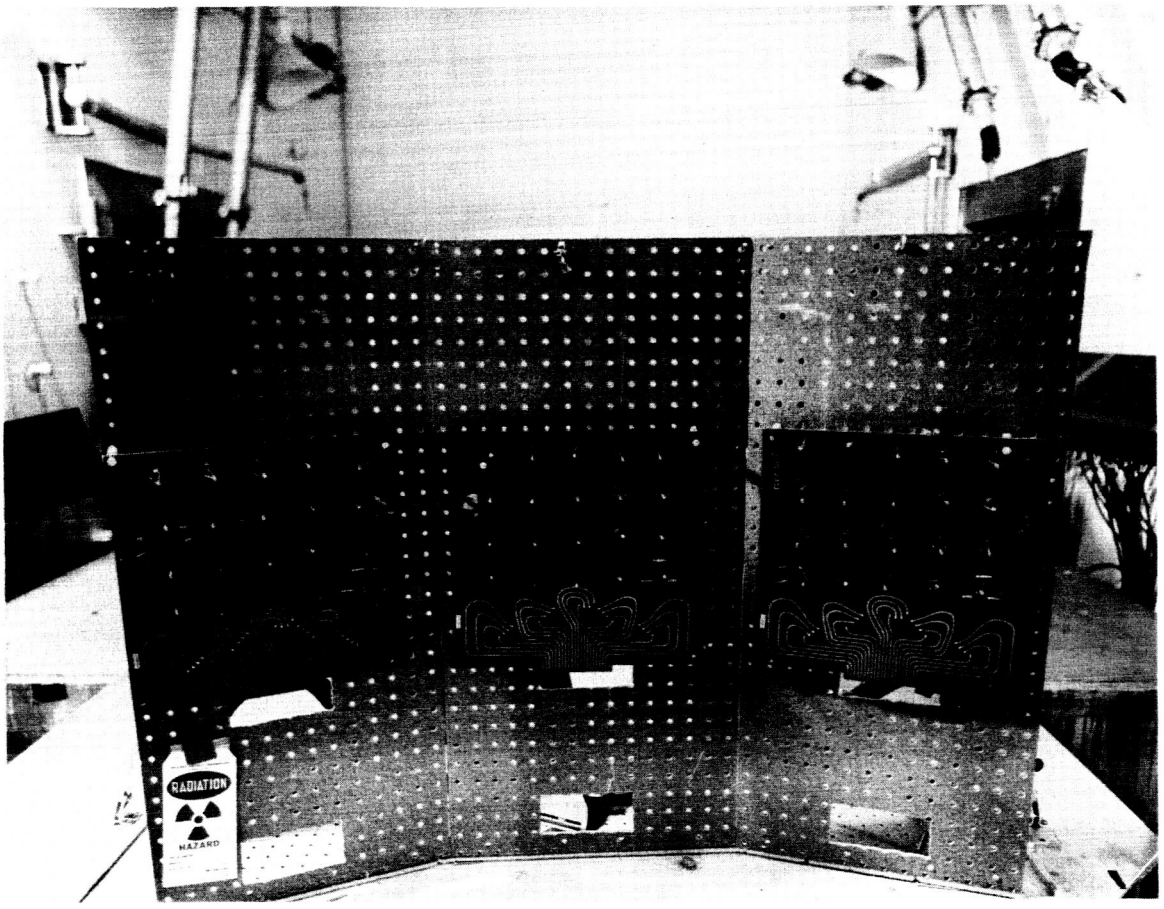
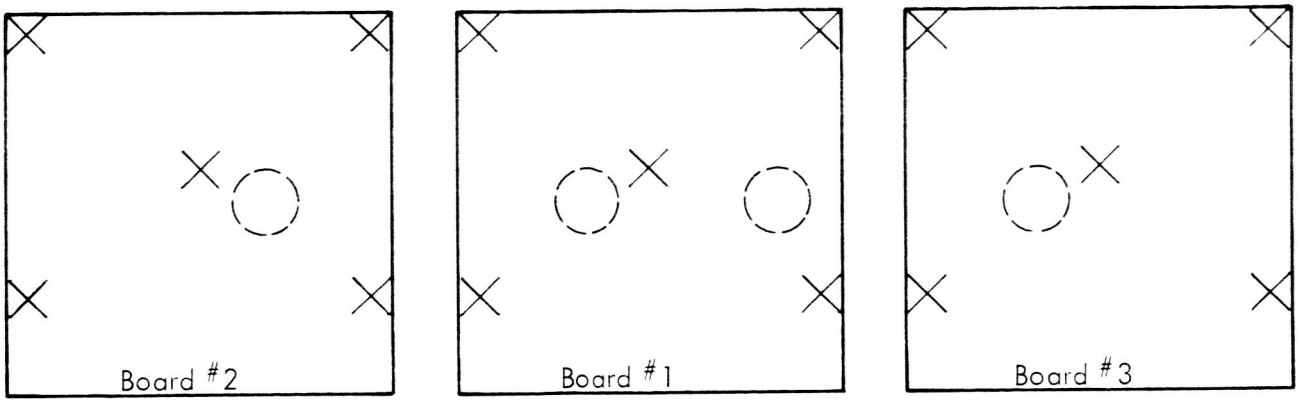


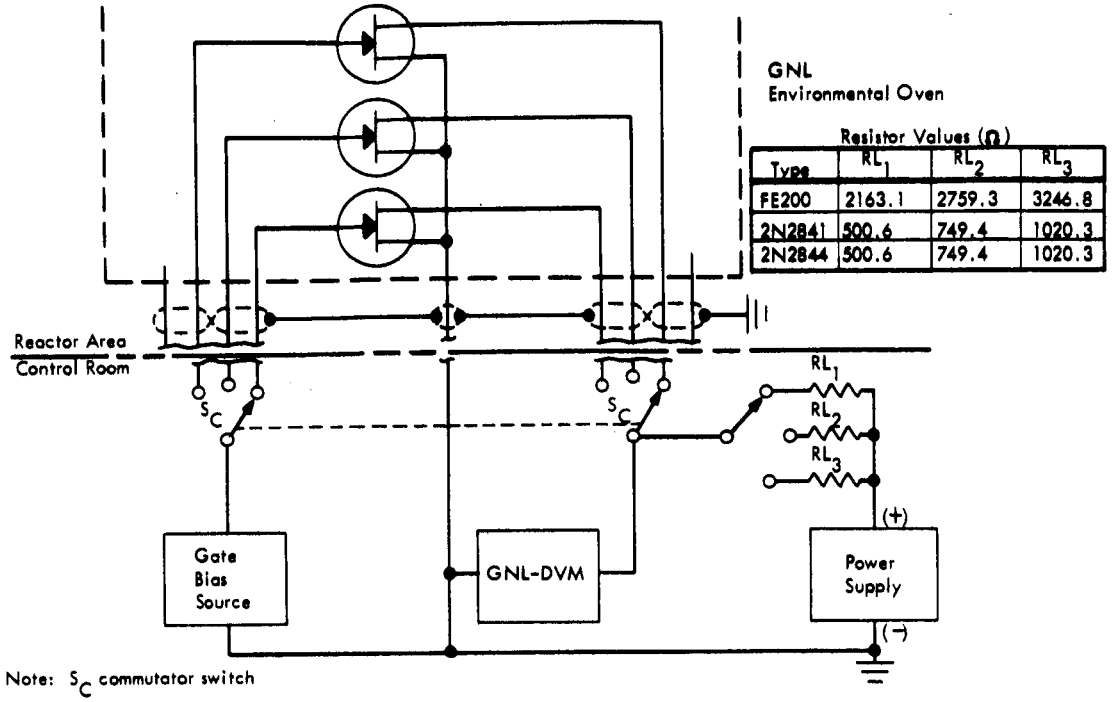
FIGURE 1 TEST PANEL



Gamma monitors located in rear of test panels

Neutron monitor foils

FIGURE 2 TEST PANEL CONFIGURATION AS SEEN FROM FRONT



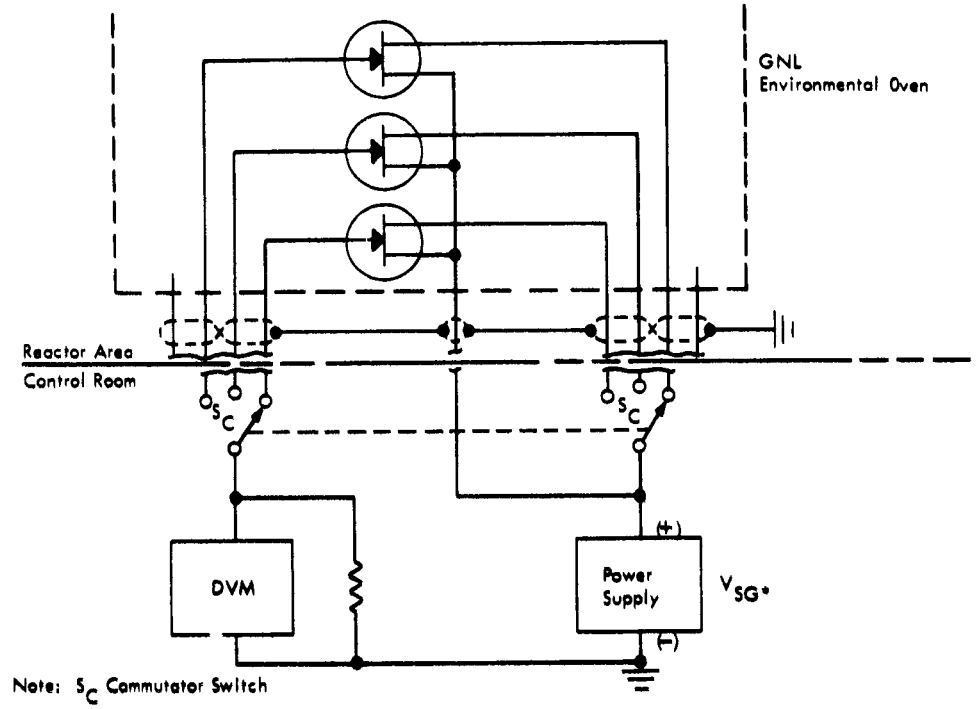
Resistor Values (Ω)

Type	RL_1	RL_2	RL_3
FE200	2163.1	2759.3	3246.8
2N2841	500.6	749.4	1020.3
2N2844	500.6	749.4	1020.3

Note: S_C commutator switch

Polarity and prescribed loads and bias were observed for P-channel transistors

FIGURE 3 FIELD EFFECT TRANSISTOR MEASUREMENT CIRCUIT



Note: S_C Commutator Switch

*Polarity of V_{SG} reversed for P-channel transistors

FIGURE 4 FIELD EFFECT TRANSISTOR LEAKAGE MEASUREMENT CIRCUIT

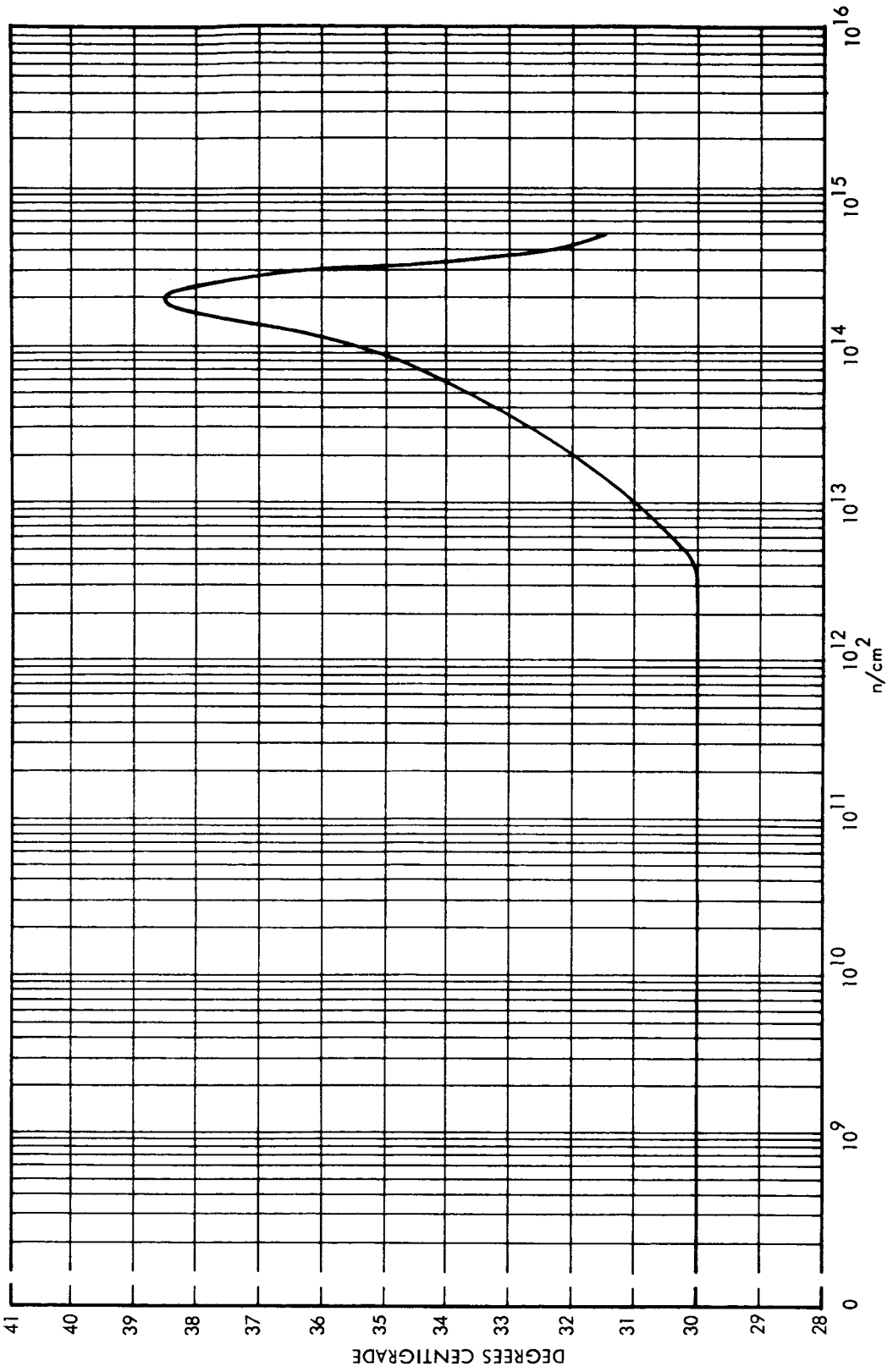


FIGURE 5 ENVIRONMENTAL TEMPERATURE VERSUS INTEGRATED NEUTRON FLUX

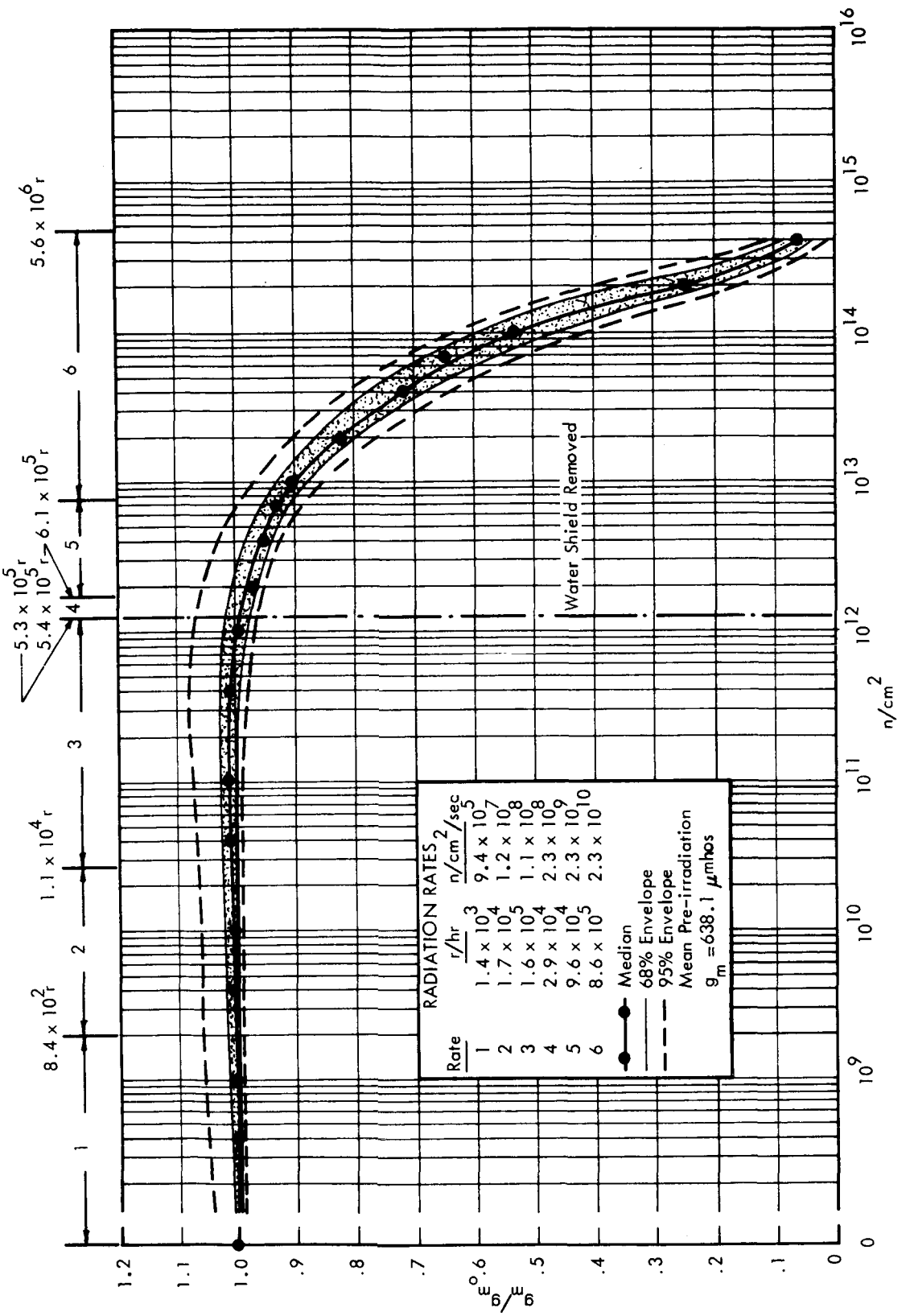


FIGURE 6 FE200 (17 SPECIMENS), NORMALIZED g_m VS. INTEGRATED NEUTRON FLUX AT T = 30°C

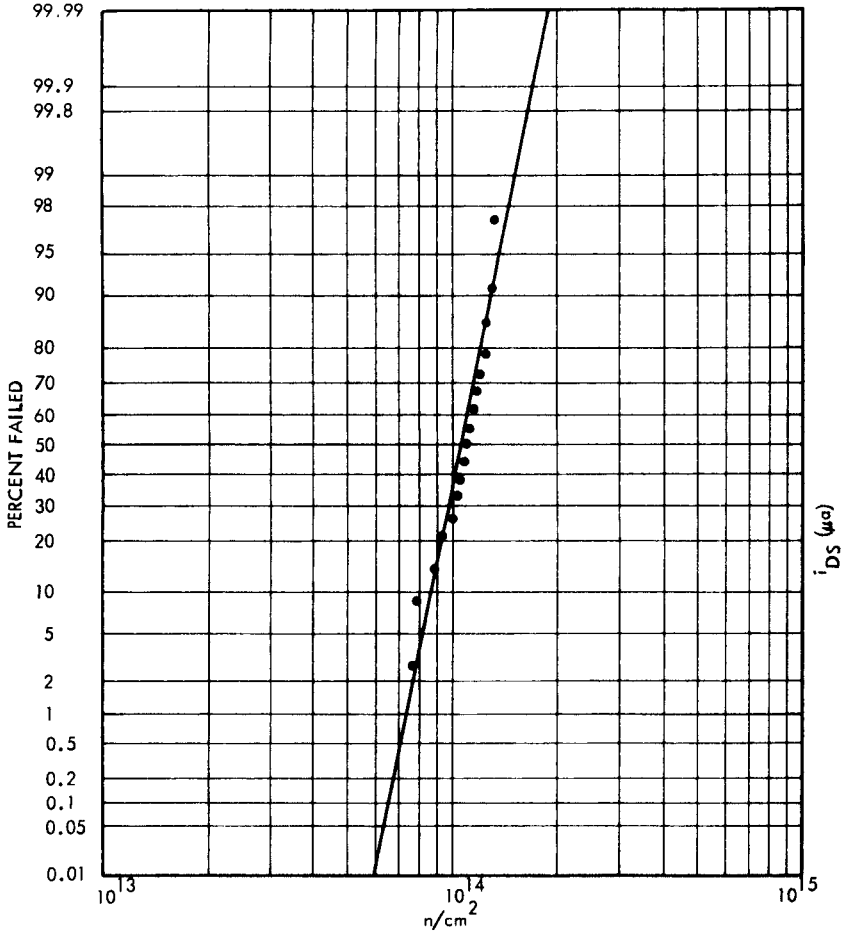


FIGURE 7 - FE 200, PERCENT FAILED VS INTEGRATED NEUTRON FLUX (FAILURE DEFINED AS $g_m/g_{m_o} \leq .5$)

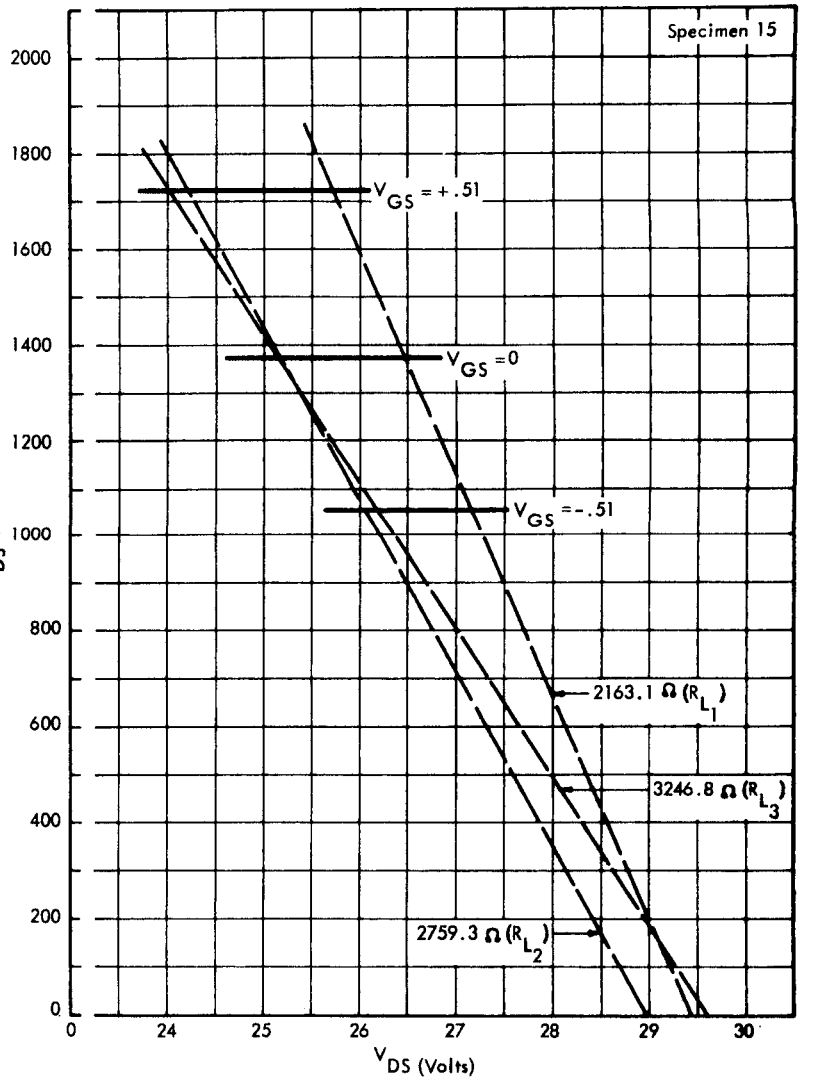


FIGURE 8 FE200 CHARACTERISTIC CURVE i_{DS} VS. V_{DS} AT T = 30°C AND nvt = 3.3×10^8 n/cm^2

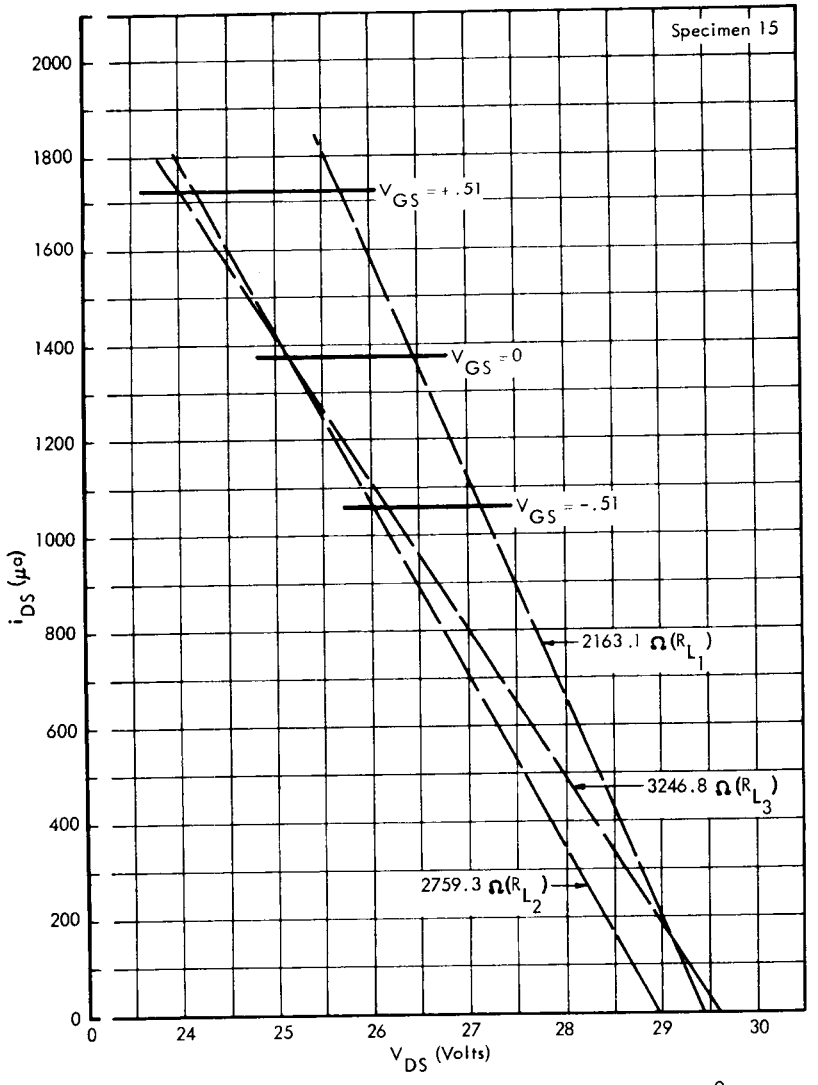


FIGURE 9 FE200 CHARACTERISTIC CURVE i_{DS} VS. V_{DS} AT T = 30°C AND nvt = 1.1×10^{11} n/cm^2

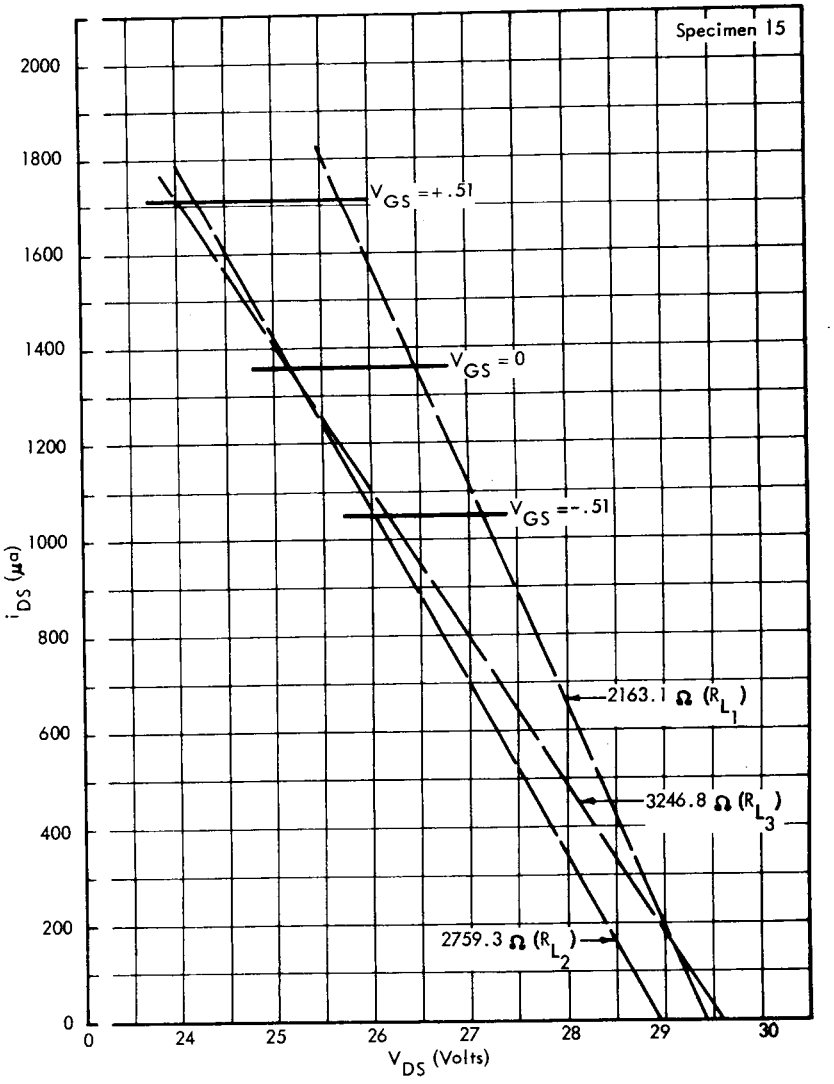


FIGURE 10 FE200 CHARACTERISTIC CURVE i_{DS} VS. V_{DS} AT T = 30°C AND nvt = 5.5×10^{11} n/cm^2

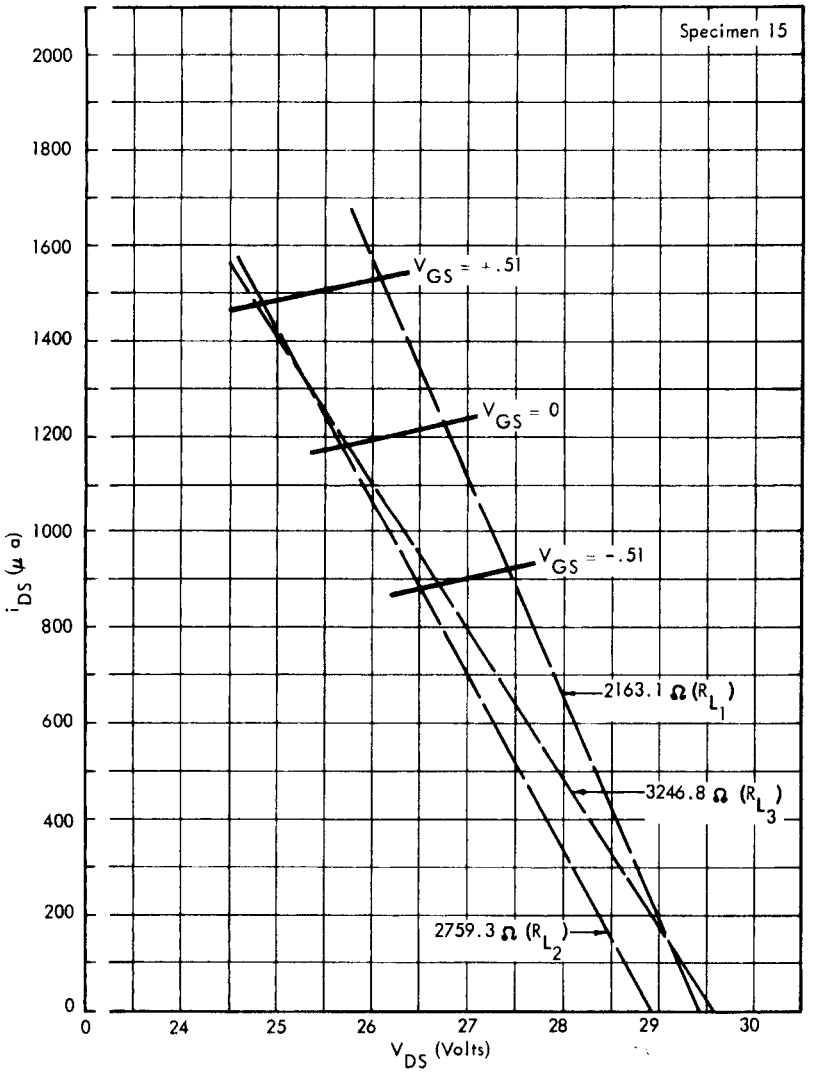


FIGURE 11 FE200 CHARACTERISTIC CURVE i_{DS} VS. V_{DS} AT T = 30°C AND nvt = 7.5×10^{12} n/cm^2

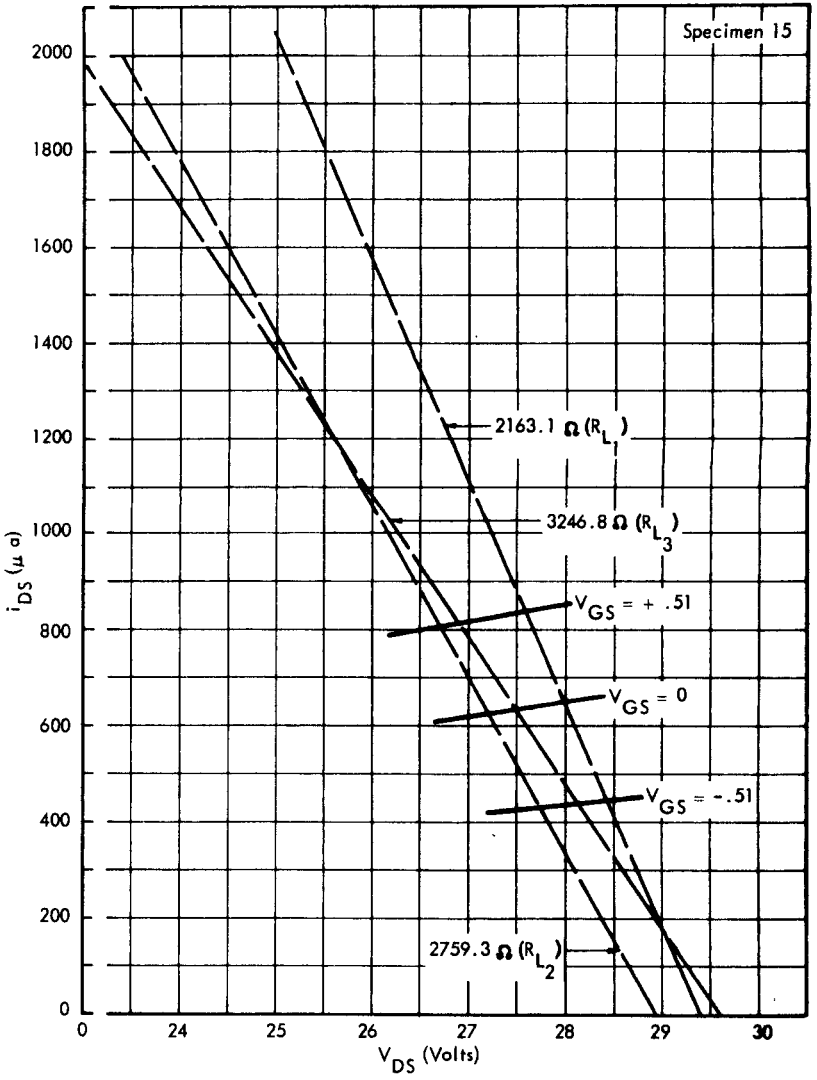


FIGURE 12 FE200 CHARACTERISTIC CURVE i_{DS} VS. V_{DS} AT T = 30°C AND nvt = 8.5×10^{13} n/cm^2

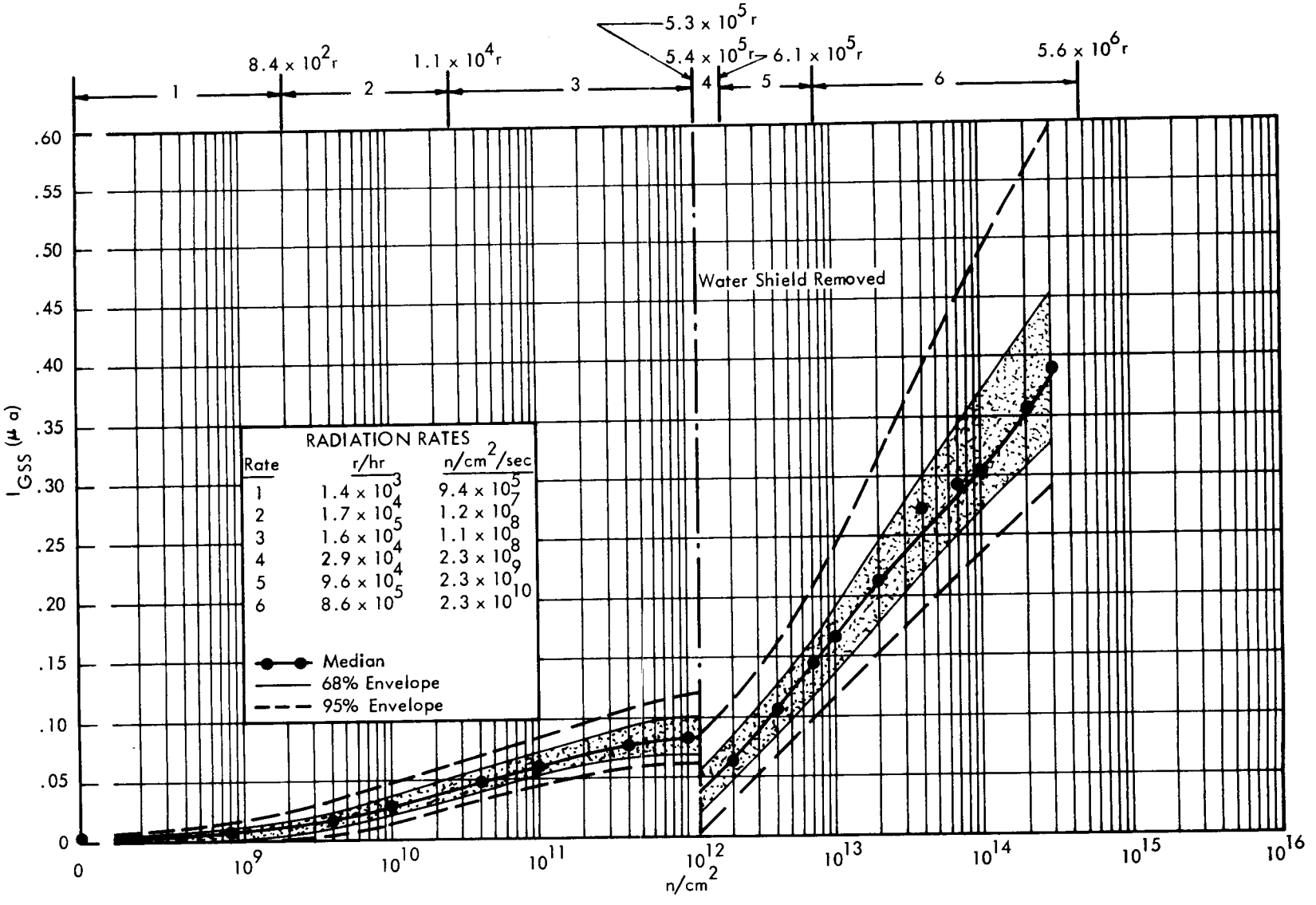


FIGURE 13 FE200 (17 SPECIMENS), I_{GSS} VS. INTEGRATED NEUTRON FLUX AT T = 30°C

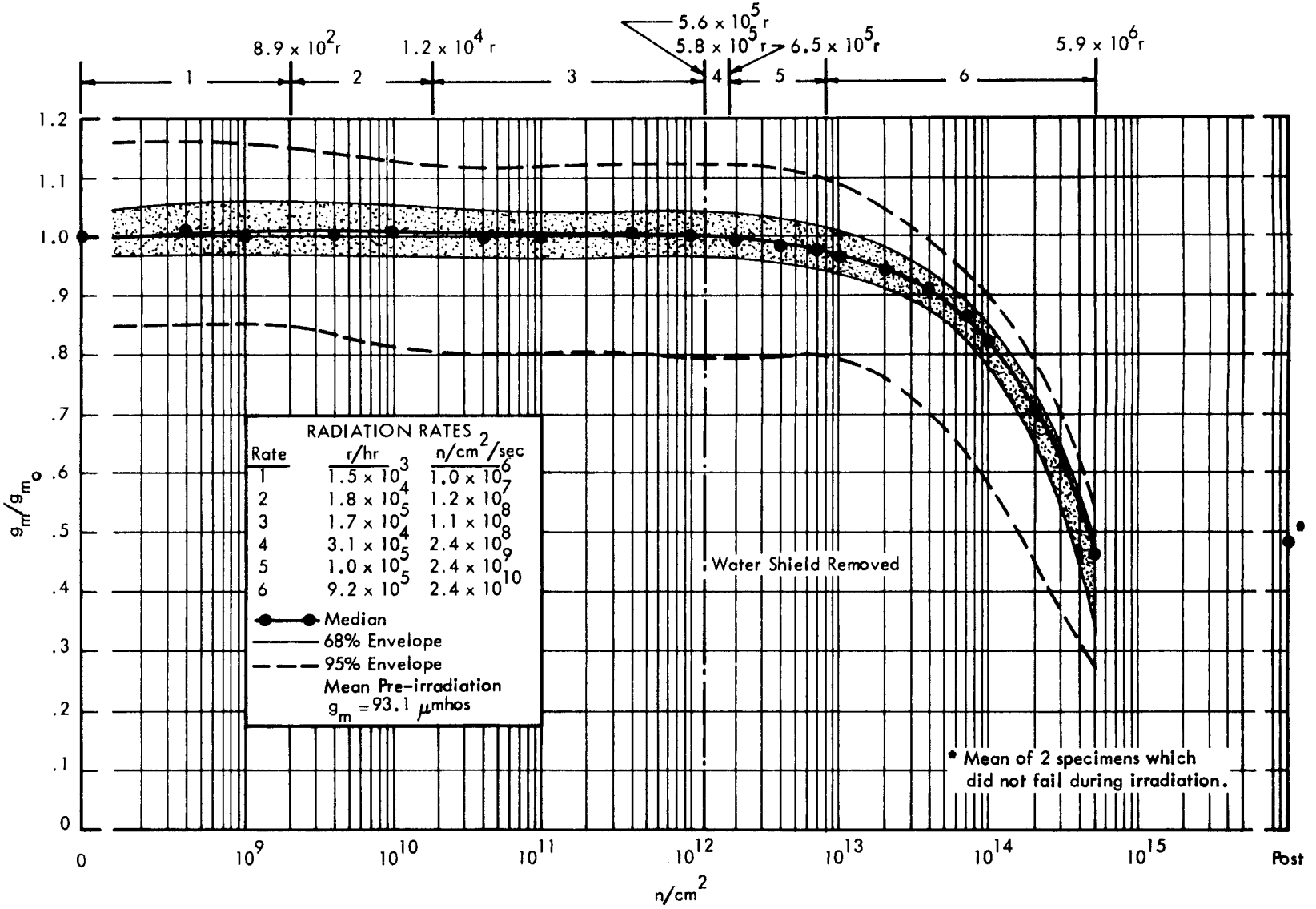


FIGURE 14 2N2841 (19 SPECIMENS) NORMALIZED g_m VS. INTEGRATED NEUTRON FLUX AT T = 30°C

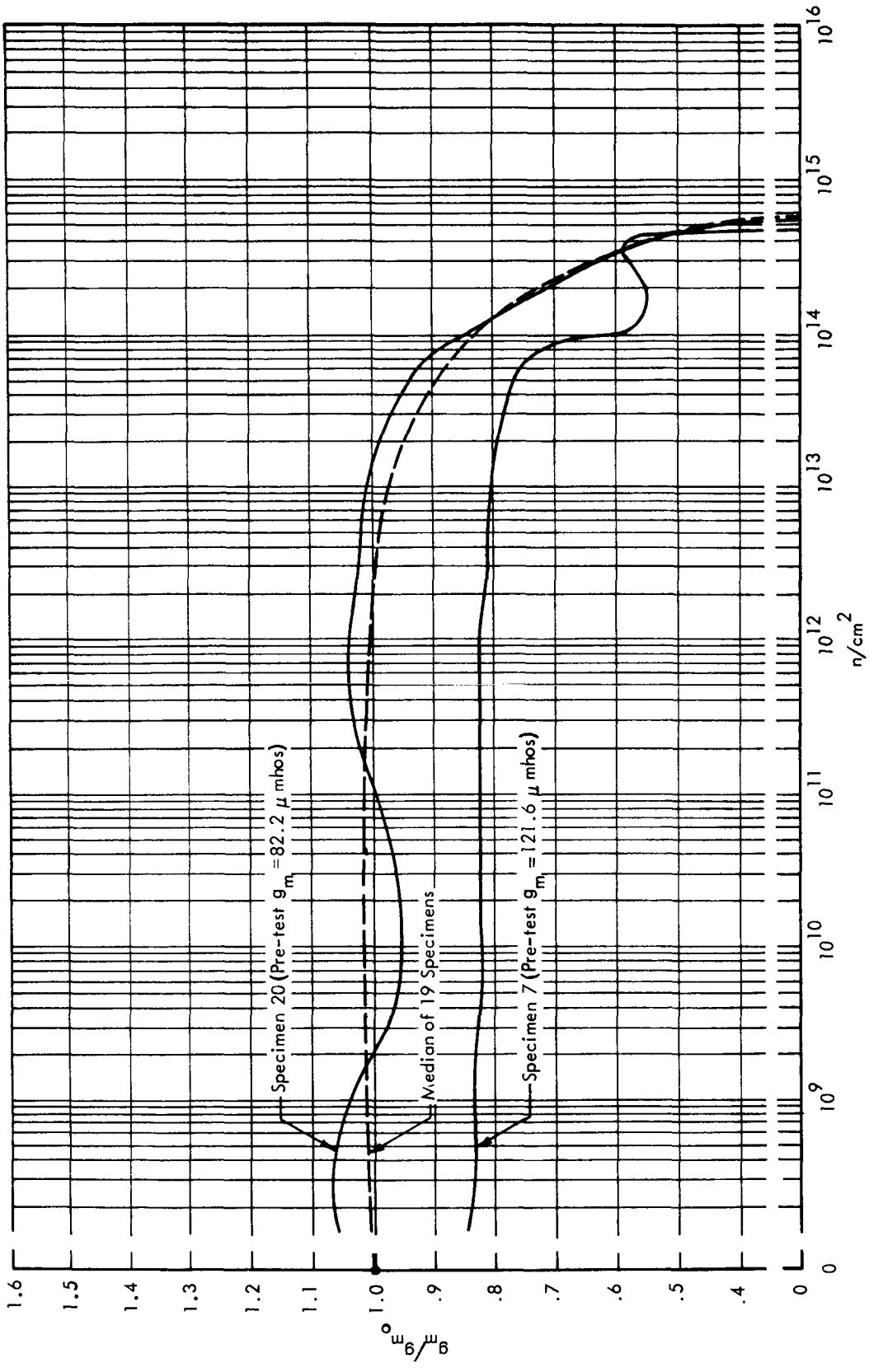


FIGURE 15 2N2841 ("UNUSUAL" SPECIMENS) NORMALIZED g_m VS. INTEGRATED NEUTRON FLUX AT T =30°C

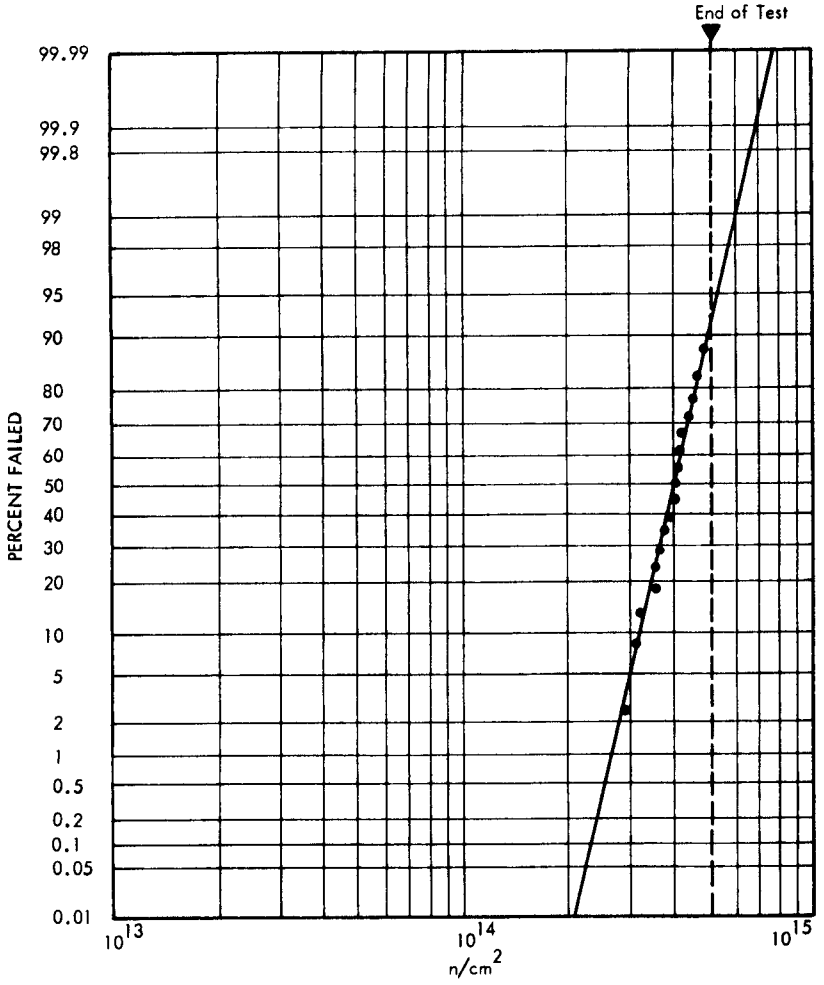


FIGURE 16 - 2N2841 (19 SPECIMENS)* PERCENT FAILED VERSUS INTEGRATED NEUTRON FLUX (FAILURE DEFINED AS $g_m/g_{m_o} \leq .5$)

*Two specimens did not fail

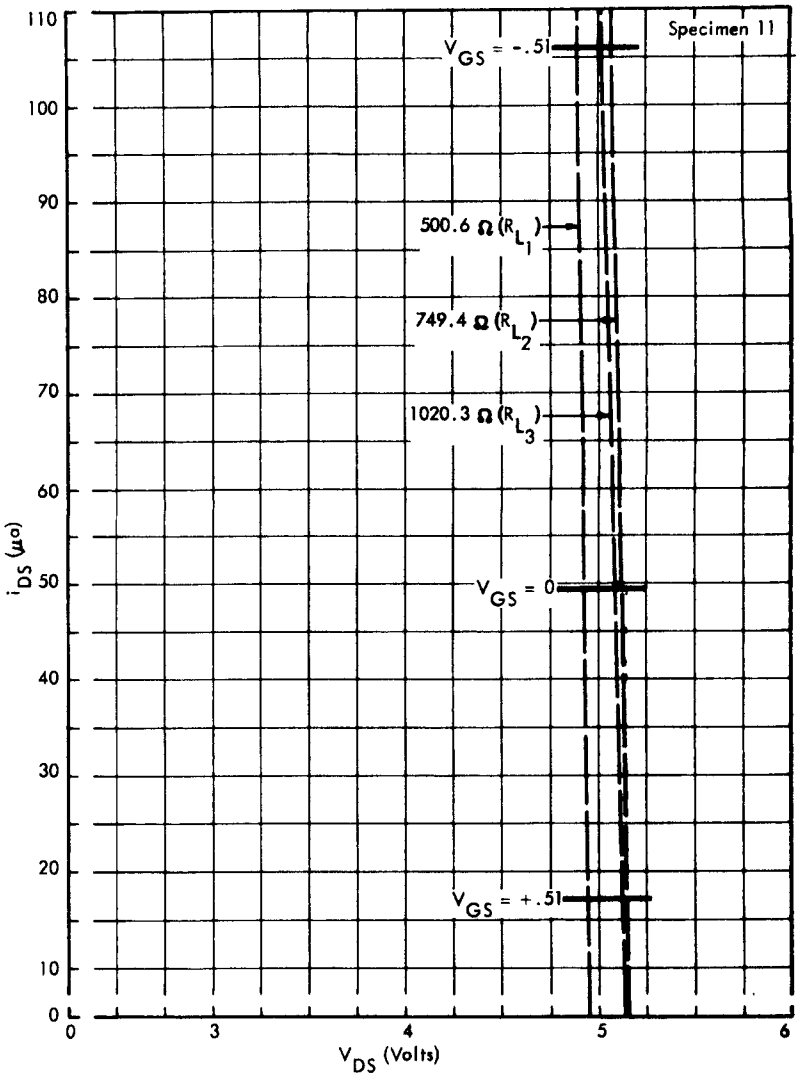


FIGURE 17 2N2841 CHARACTERISTIC CURVE i_{DS} VS. V_{DS} AT T = 30°C AND nvt = 1.0 X 10^9 n/cm^2

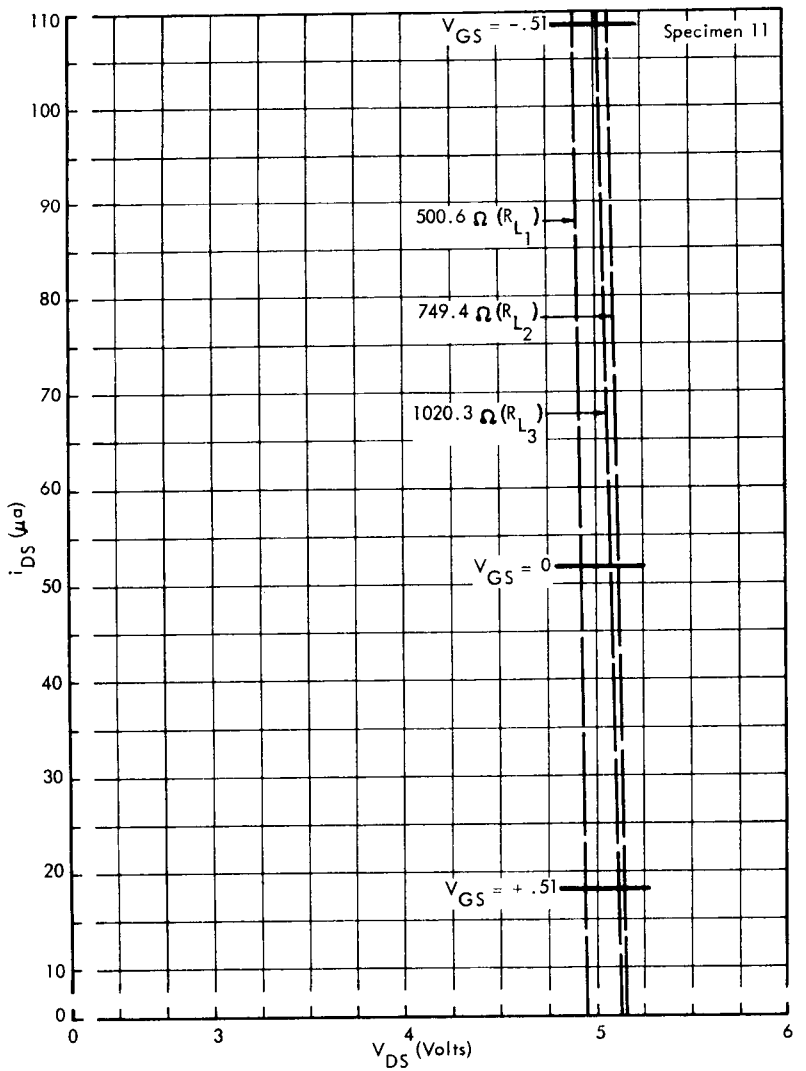


FIGURE 18 2N2841 CHARACTERISTIC CURVE i_{DS} VS. V_{DS} AT T = 30°C AND nvt = 1.8×10^{11} n/cm^2

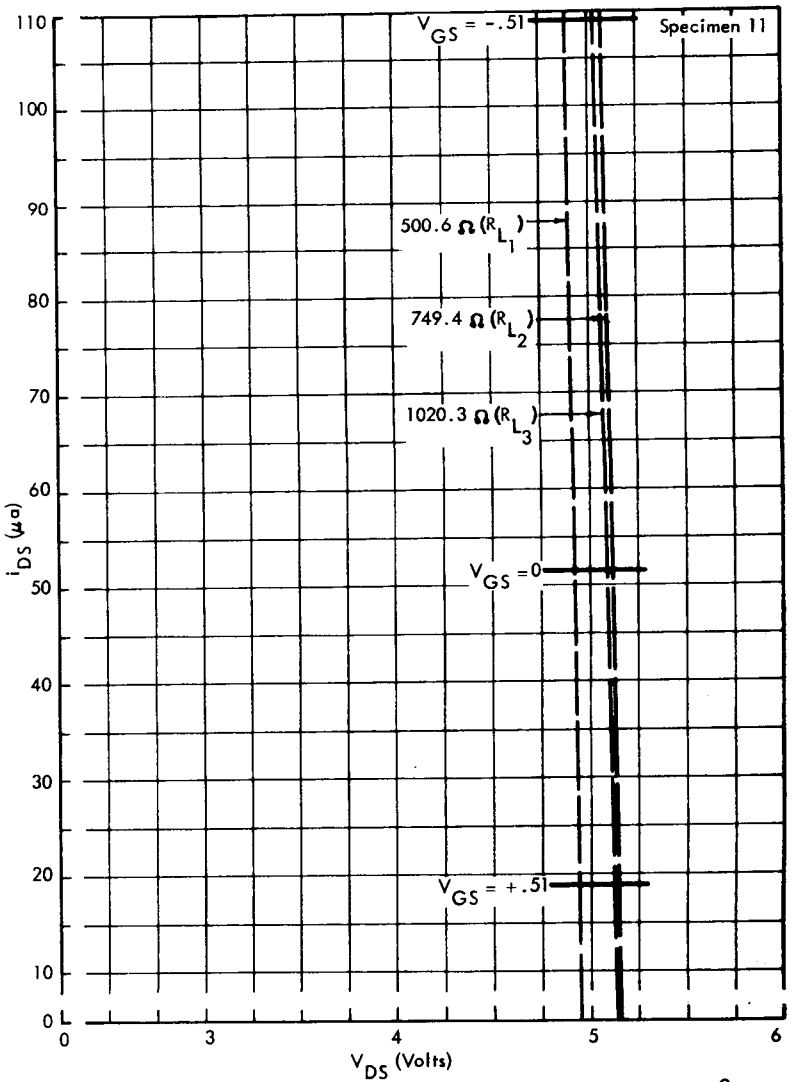


FIGURE 19 2N2841 CHARACTERISTIC CURVE i_{DS} VS. V_{DS} AT T = 30°C AND nvt = 6.6×10^{11} n/cm^2

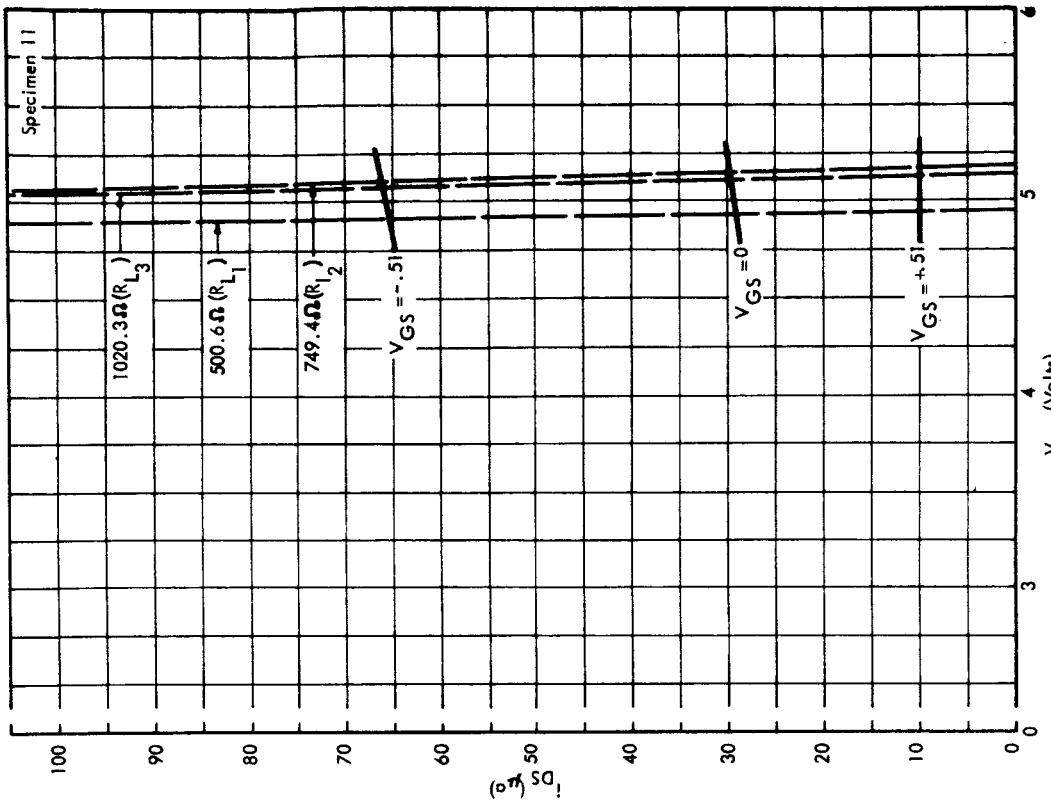


FIGURE 21 2N2841 CHARACTERISTIC CURVE i_{DS} VS. V_{DS} AT T = 30°C AND nvt = 1.5×10^{14} n/cm^2

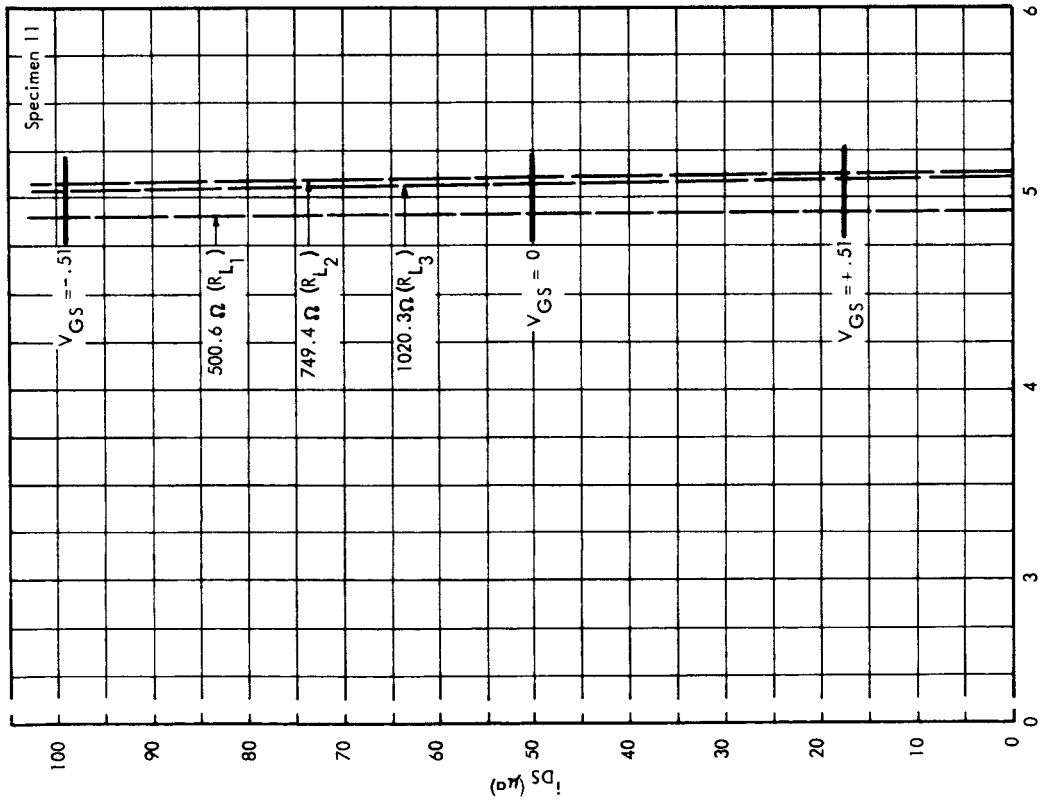


FIGURE 20 2N2841 CHARACTERISTIC CURVE i_{DS} VS. V_{DS} AT T = 30°C AND nvt = 4.9×10^{13} n/cm^2

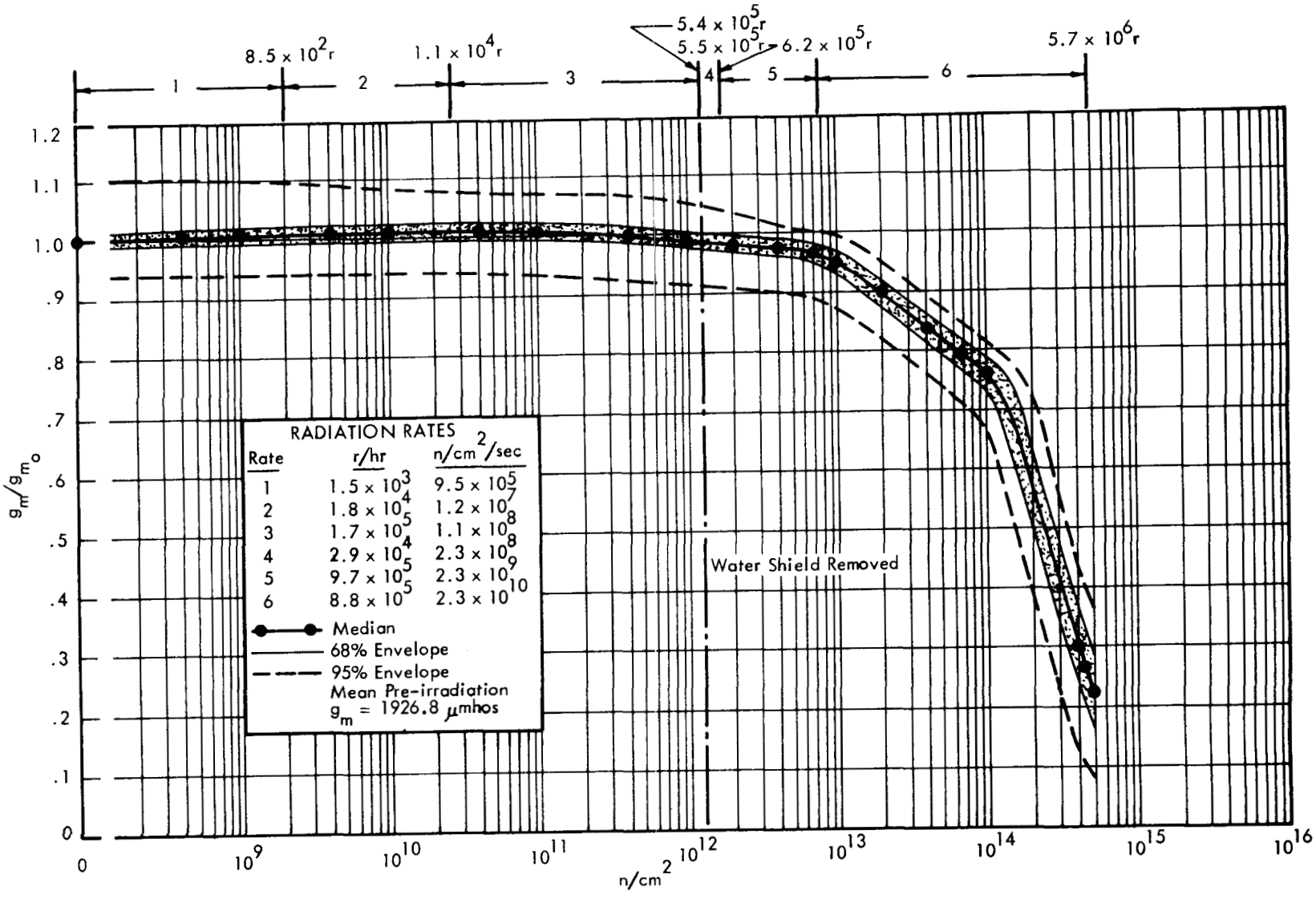


FIGURE 22 2N2844 (17 SPECIMENS) NORMALIZED g_m VS. INTEGRATED NEUTRON FLUX AT T = 30°C

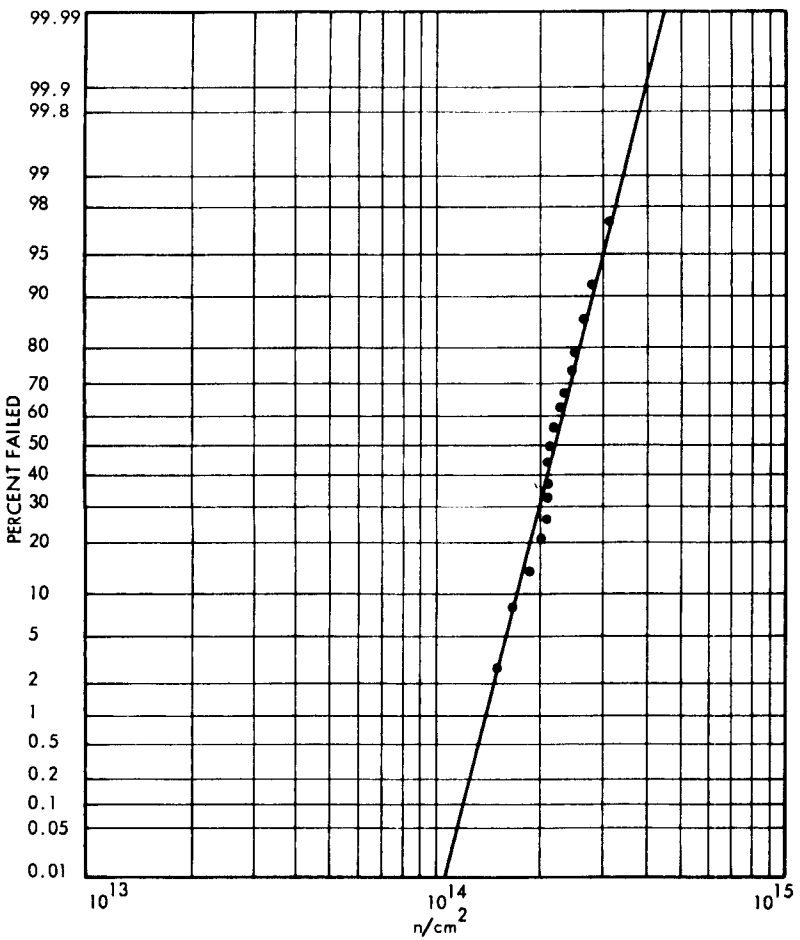


FIGURE 23 2N2844 (17 SPECIMENS) PERCENT FAILED VS. INTEGRATED NEUTRON FLUX (FAILURE DEFINED AS $g_m/g_{m_o} \leq .5$)

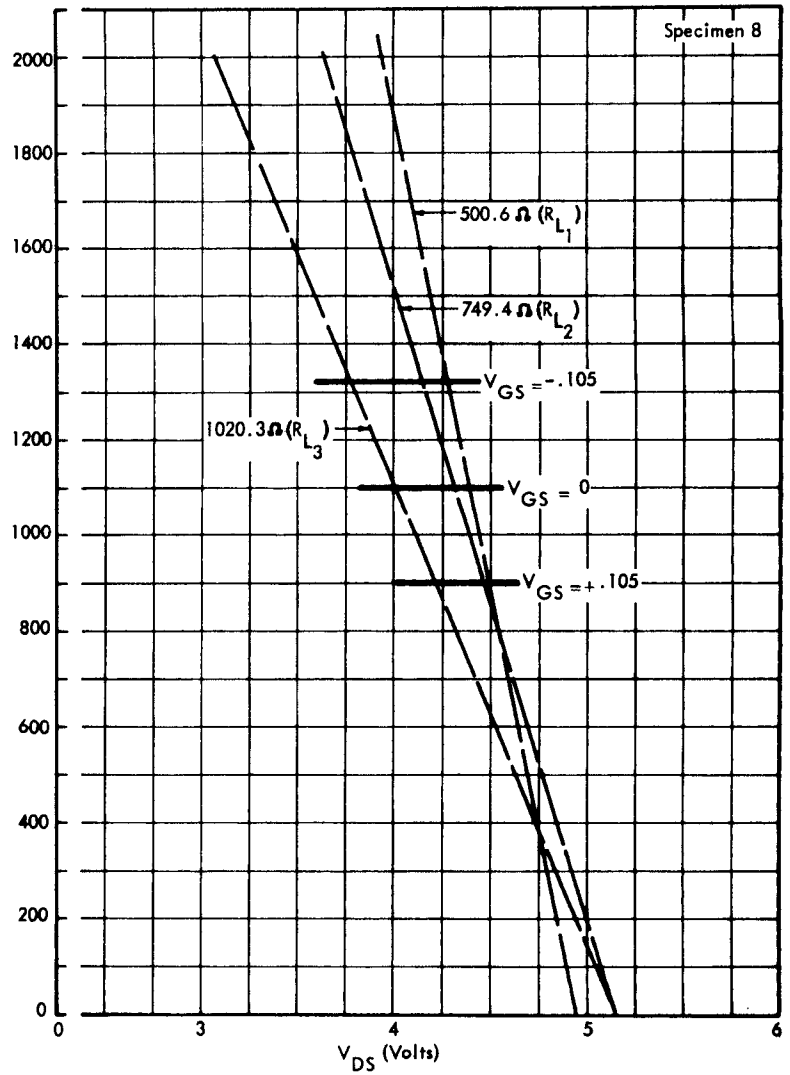


FIGURE 24 2N2844 CHARACTERISTIC CURVE i_{DS} VS. V_{DS} AT T = 30°C AND nvt = 1.5×10^9 n/cm^2

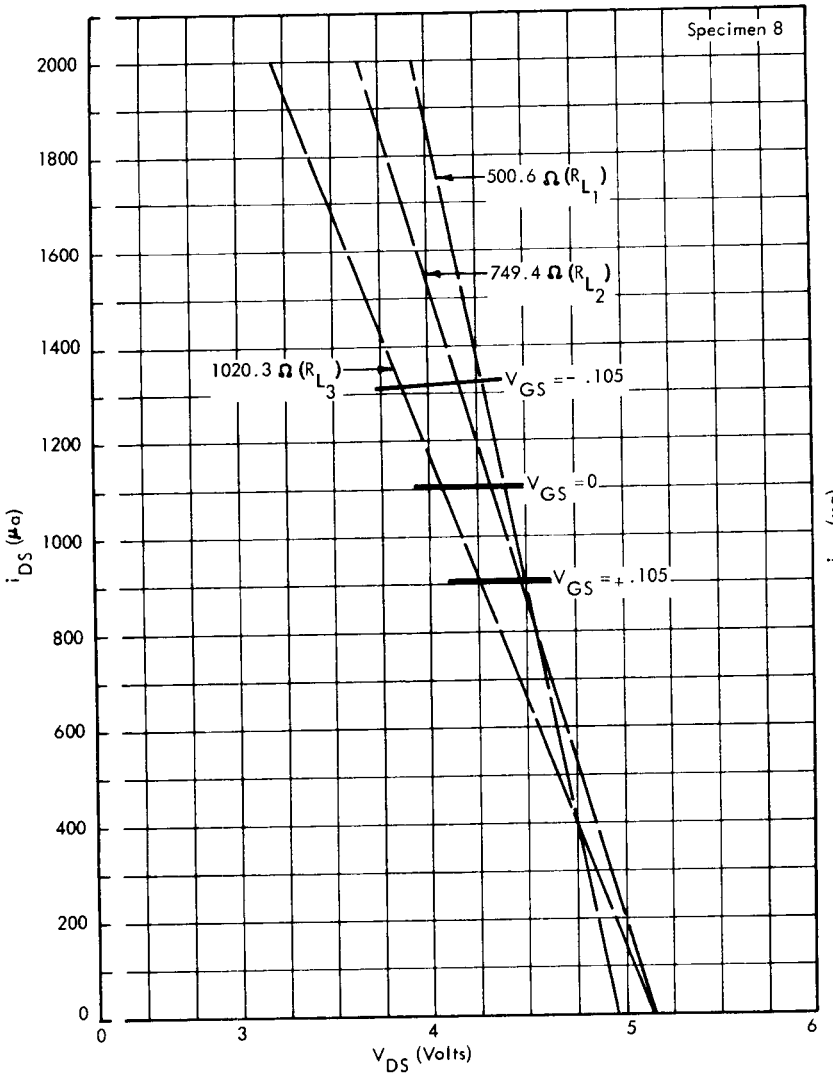


FIGURE 25 2N2844 CHARACTERISTIC CURVE i_{DS} VS. V_{DS} AT T = 30°C AND nvt = 2.3×10^{11} n/cm^2

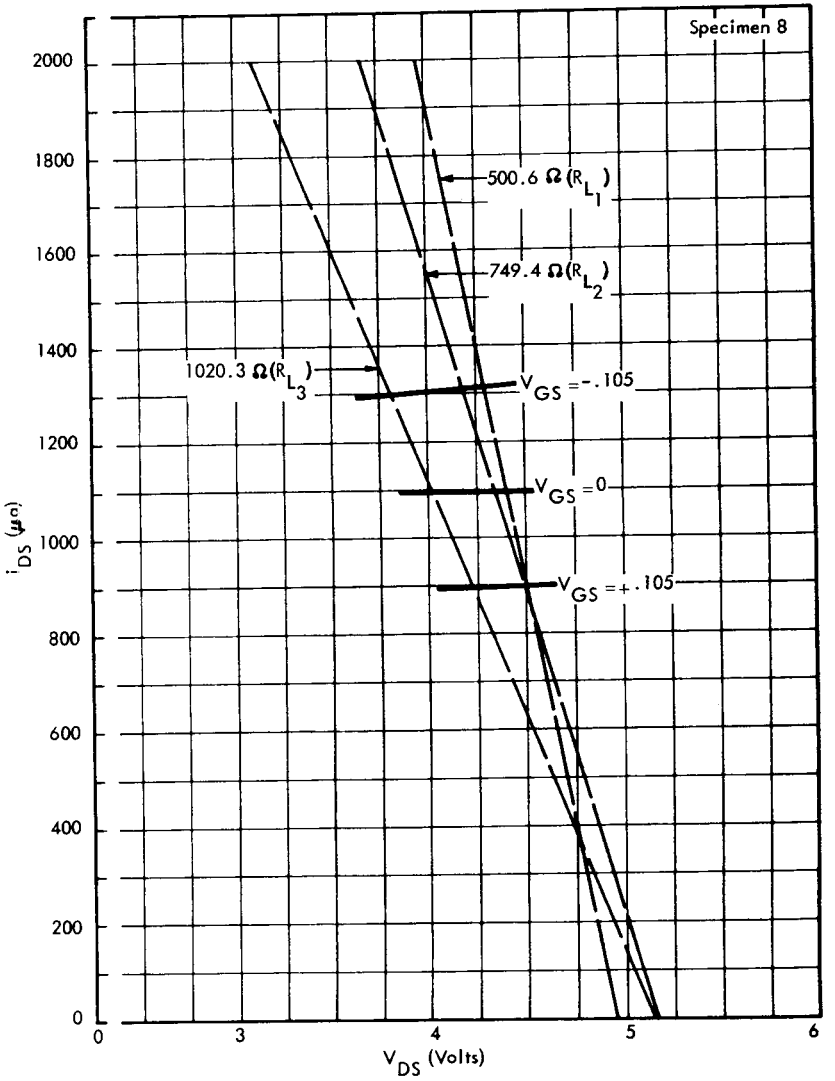


FIGURE 26 2N2844 CHARACTERISTIC CURVE i_{DS} VS. V_{DS} AT T = 30°C AND nvt = 6.9×10^{11} n/cm^2

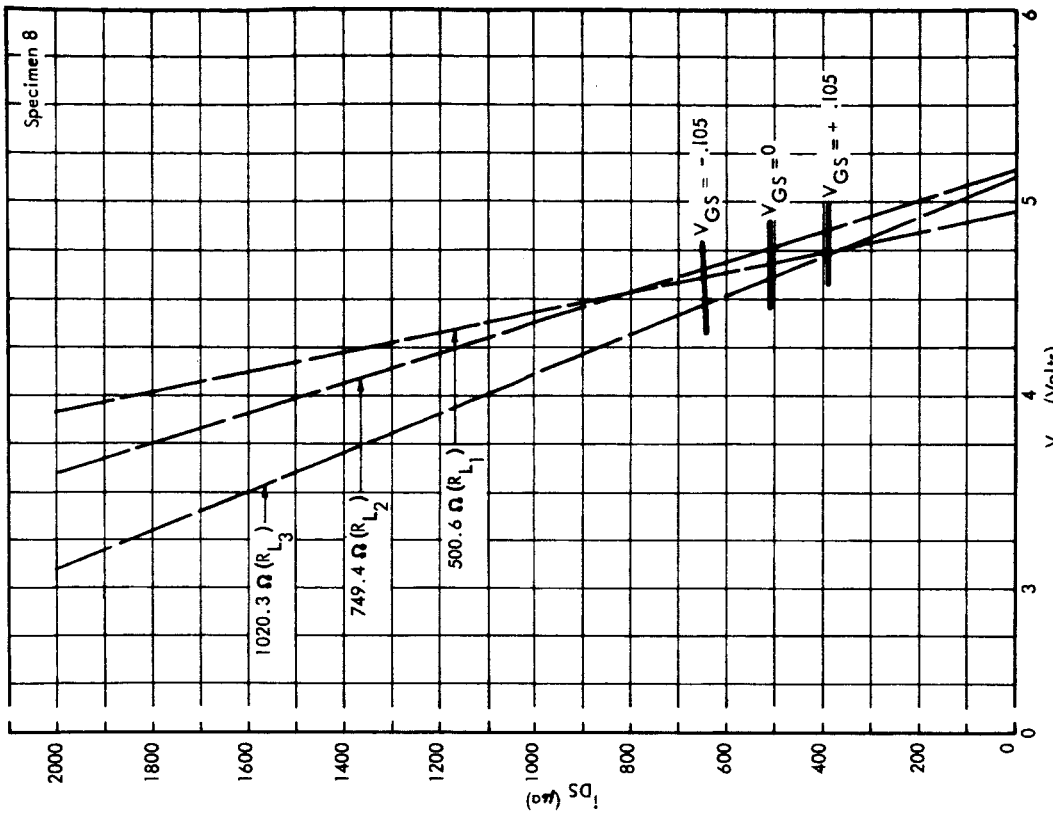


FIGURE 28 2N2844 CHARACTERISTIC CURVE i_{DS} VS. V_{DS} AT T = 30°C AND nvt = 1.5×10^{14} n/cm^2

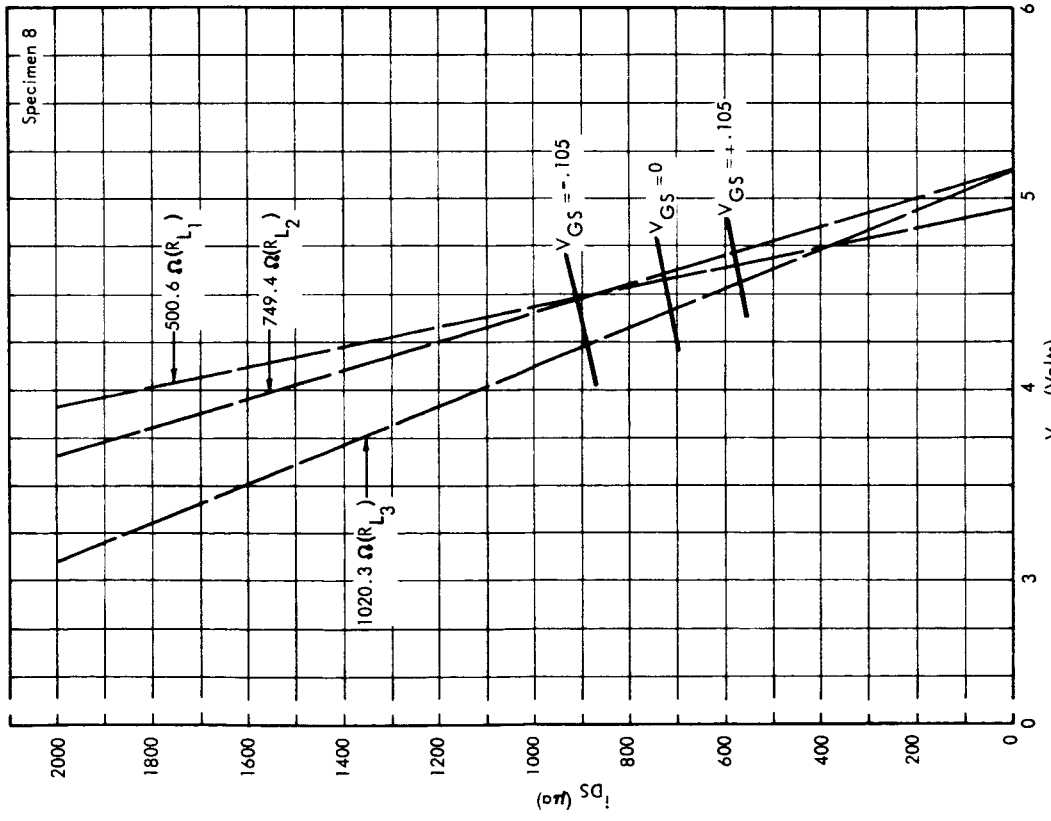


FIGURE 27 2N2844 CHARACTERISTIC CURVE i_{DS} VS. V_{DS} AT T = 30°C AND nvt = 7.4×10^{13} n/cm^2

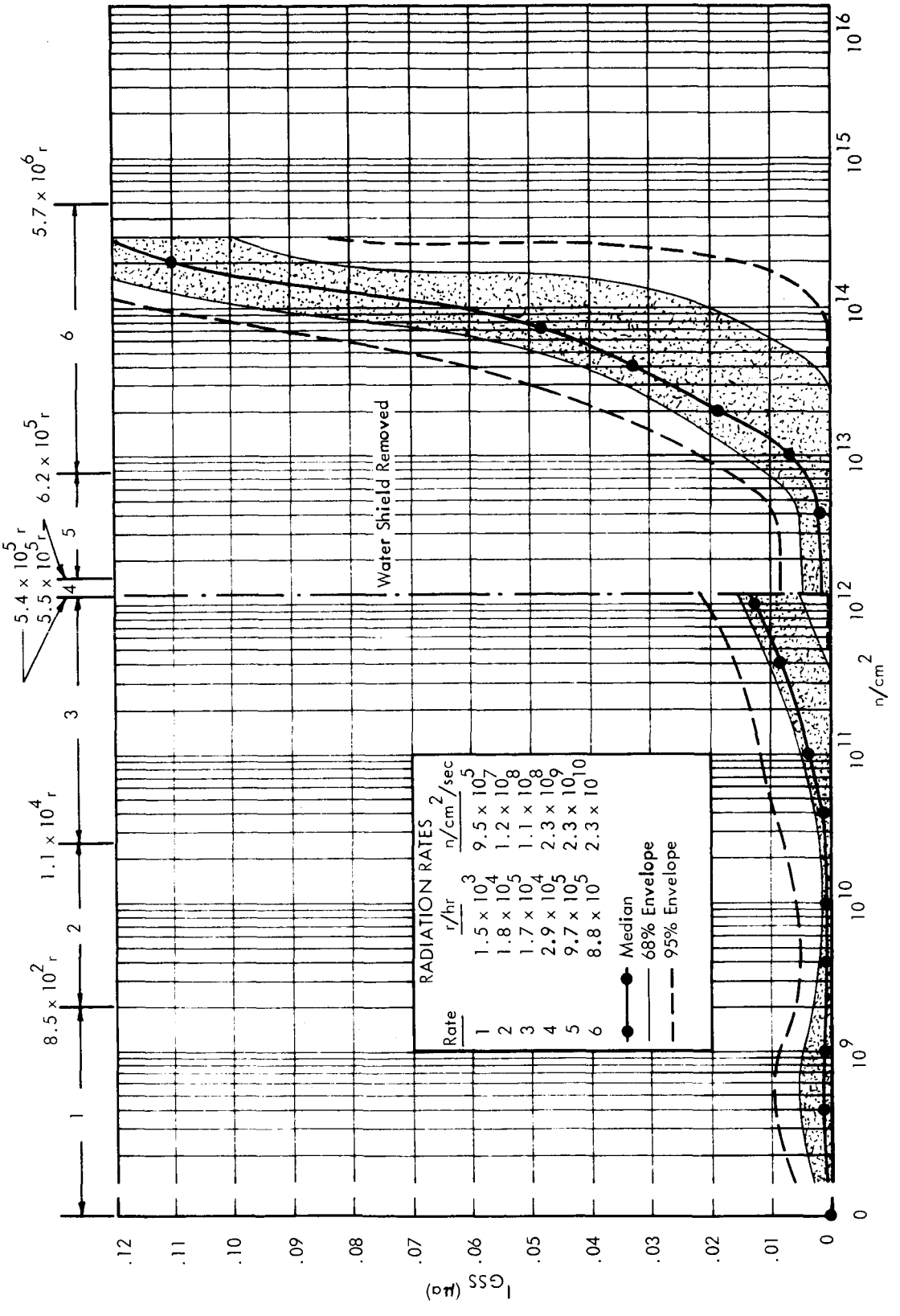


FIGURE 29 2N2844 (15 SPECIMENS) I_{GSS} VS. INTEGRATED NEUTRON FLUX AT T = 30°C